# ESTIMATION OF SOIL LOSS USING GEOGRAPHIC INFORMATION SYSTEM

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Universiti Malaysia Sarawak
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# ESTIMATION OF SOIL LOSS USING GEOGRAPHIC INFORMATION SYSTEM

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## BORANG PENYERAHAN TESIS

Judul: Estimation of Soil Loss Using Geographic Information System

**SESI PENGAJIAN:** 1998/1999

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This project report attached here to, entitled " ESTIMATION OF SOIL LOSS USING GIS ", prepared by JEFFEERY WONG LIN KEE in partial fulfilment of requirement for Bachelor Degree of Engineering (CIVIL) with Honours is hereby accepted.

| | |
|---|---|
| 03.10.98 | |
| (Dr Nabil Bessaih) | Date |
| Project Surpervisor | |
| | 10.10.98 |
| (Dr Wang Ying Chai) | Date |
| Project Supervisor | |

**To My Beloved Family & Friends**

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# ABSTRACT

Rapid development in Sarawak and the government intention in turning the rural areas into palm oil plantation for the last few years cause rapid deforestation. This will endanger the watersheds, as deforestation will cause soil erosion, thus introduce sediment into our water resources. This thesis introduces soil erosion computation with different cover factors using Geographic Information System (GIS). A simple GIS-based soil erosion model had been proposed. The model was constructed from coupling the ARC/INFO GIS system with the Universal Soil Loss Equation (USLE) model. The USLE has been used for a number of years to predict the soil erosion rates. The USLE parameters; rainfall erosivity, slope length gradient, cover factor, soil erodibility and conservation factor were generated into relevant layers for soil erosion spatial modelling in the ARC/INFO. The method involves spatial disaggregation of different coverages such as land use and topography into uniform cell-size of 200' x 200'. Using the map algebra, which has the computational abilities, the different cells and parameters were calculated to produce the soil erosion values and generate the soil erosion risk maps. These maps will be useful for planning the land development activities in the future and estimating the severity of soil sedimentation into the Bakong River.

# ABSTRAK

Pembangunan yang pesat di Sarawak beberapa tahun kebelakangan ini menyebabakan banyak hutan dimusnahkan. Ini akan merosakkan kawasan tadahan air kerana pemusnahan hutan akan mengakibatkan hakisan tanah, justeru itu membawa kelodak ke dalam sumber-sumber air kita. Tesis ini cuba mengkaji nilai anggaran hakisan tanah dan menghasilkan peta hakisan tanah untuk Ladang Kelapa Sawit Binu di Bakong. Ini dilakukan dengan menggunakan 'Geographic Information System' (GIS) yang diintegrasikan dengan 'Universal Soil Loss Equation' (USLE) bagi pelbagai jenis tumbuhan yang bertindak sebagai tanaman tutup bumi. Sistem ARC/INFO GIS digunakan dalam projek ini. USLE telah digunakan sekian lama untuk menganggarkan nilai hakisan tanah. Parameter-parameter di dalam USLE ditukar kepada bentuk grid. Misalnya, garisan-garisan kontur ditukarkan kepada bentuk grid 200' x 200'. Dengan menggunakan 'map algebra' yang mempunyai fungsi menghitung, grid-grid yang berlainan ini akan didarab bersama untuk menghasilkan nilai dan peta hakisan tanah. Peta-peta yang dihasilkan adalah berguna untuk perancangan pembangunan pada masa hadapan supaya nilai hakisan tanah dapat dikurangkan.

# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

Erosion of the earth's surface is a slow, but dynamic, natural process of smoothing and levelling, and is fundamental to the formation of alluvial soils and sedimentary rocks. The forces of nature cause geological, natural or normal erosion, and accelerated erosion is caused by human interference. The human being, via faulty agriculture, forest fires, industrialisation, urbanisation, tourism, pollution, etc. destroys nature to an extent that no other living creature possibly can.

Erosion is not a local problem anymore; it is a global disaster. In the recent years, erosion has been discussed extensively. Various scientists, environmental organisations, foundations and associations managed to draw public attention to the issue and raise the level of general consciousness about erosion. The alienation of the modern man from nature has decreased his awareness and sensitivity to it. The future perils include famine, drought, and collapse of agriculture, mass immigration and social crisis.

Land seems like an endless resource, on which humans continue their socio-economic activities such as agriculture, transportation, mining, etc. However, the soil on which life can exist is only a few centimetres thick and took millions of years to form. Along with air and water, soil is a primary source of life and we are gradually losing it. Life can not exist without soil.

## 1.1 Application of GIS in Soil Erosion

Throughout the competent and regional agrarian authorities, it is still usual practice to work out erosion-calculations for land consolidation operations manually by means of tables and diagrams on a map of the consolidation area. This method consumes lots of time and limits to those experts in it only. The acquisition of Geographical Information Systems (GIS) and program systems for the generation of Digital Terrain Models (DTM), opens new efficient methods and processes to approximate the erosion-endangering. An important precondition was the development of new, powerful and cheap computing systems, e.g. personal computers or workstations.

Simple and complex soil erosion can be coupled with a GIS for improved soil erosion prediction, while reducing the time needed for model parameterization. This report is based on a design project to study the soil erosion at Bakong watershed area. GIS and a simple soil erosion prediction model, Universal Soil Loss Equation (USLE) were used to predict soil erosion and over-land sediment transport on 200-square-feet grids across 18 080 hectares of a selected area at Bakong watershed area, for a range of alternative management practices. The final outputs are the soil erosion risk maps. These maps were compared to view the soil erosion differences in ton/year when the cover factors varied.

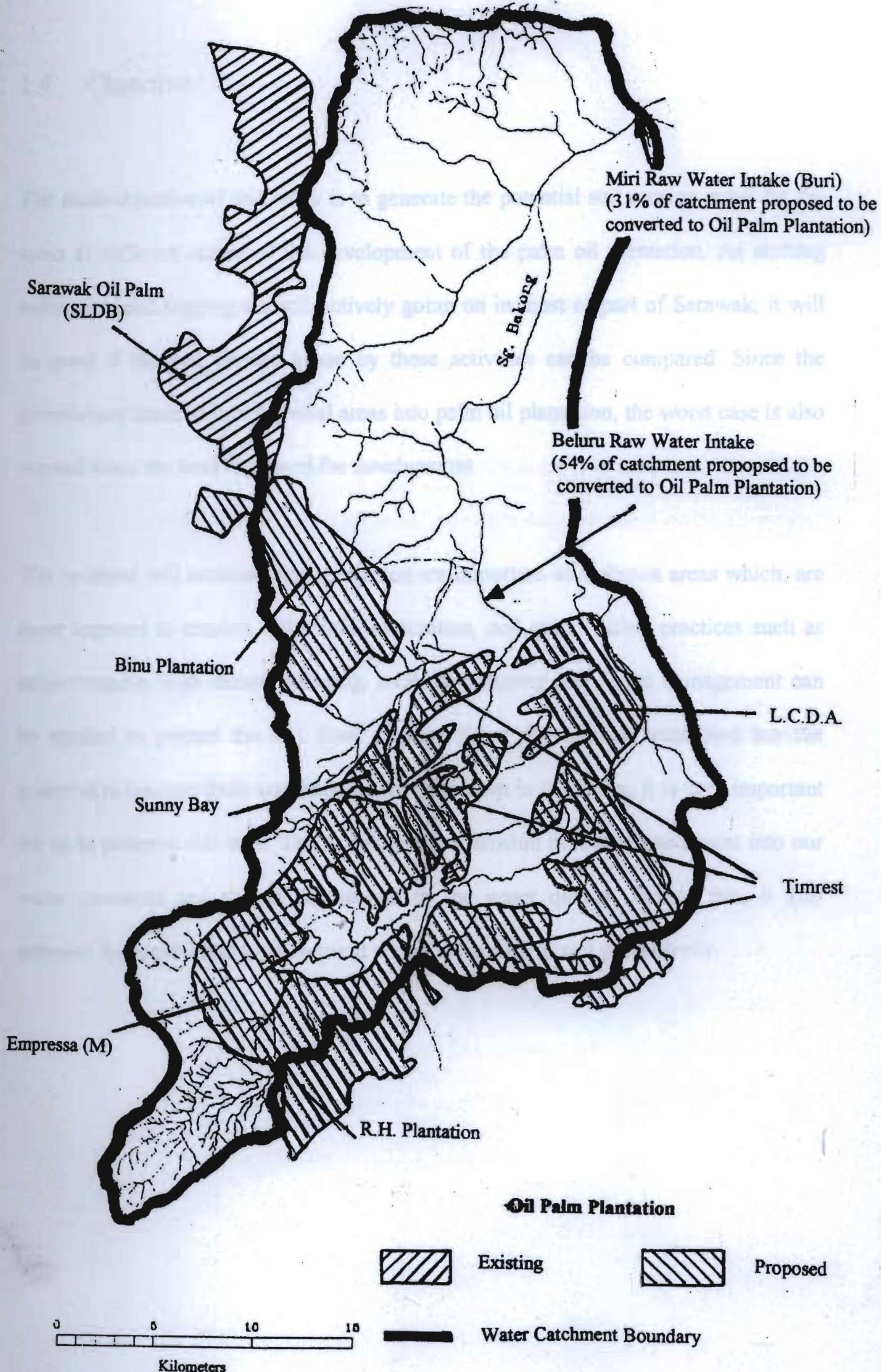
## 1.2 Study Area

Bakong watershed area is located at north region of the state of Sarawak in Miri division, Malaysia. Parts of the watershed area are swampland. The study area covers only part of the Bakong watershed area, which was developed into the Binu palm oils plantation. Binu plantation lies approximately within latitudes 3.9 $^{0}$N and 4.0 $^{0}$N and longitudes 114.0 $^{0}$E and 114.15 $^{0}$E, encompassing Bakong River and its tributaries. It covers an area about 180.8 $km^2$ or 18 080 hectares. Its preliminary land use was mainly primary undisturbed forest although shifting cultivation together with grassland or brush land covered part of the watershed. The climate is characterised by an annual precipitation 3190mm and average temperature of 28$^{0}$ C.

## 1.3 Materials

1. UNIX based computer with ARC/INFO software for GIS application.
2. Digitiser and digitiser pad.
3. Rainfall data.
4. Soil maps.
5. Topographic maps at scale 1:50 000.

**Bakong Water Catchment**



## 1.4 Objective

The main objective of this study is to generate the potential soil erosion maps for the areas at different stages of the development of the palm oil plantation. As shifting cultivation and logging are still actively going on in most of part of Sarawak, it will be good if the soil erosion cause by these activities can be compared. Since the government tends to turn the rural areas into palm oil plantation, the worst case is also viewed when the land is cleared for development.

The potential soil erosion maps generated are important as it shown areas which, are more exposed to erosion. With this information, soil conservation practices such as strip-cropping, high density planting, multiple cropping and forest management can be applied to protect the soil from erosion. Since the Bakong watershed has the potential to become fresh water source for Miri town in the future, it is very important for us to preserve this area. This is because soil erosion introduced sediment into our water resources and this is detrimental to the water quality. Beside this, it also removes the topsoil and plant nutrient which is harmful to soil productivity.

## 1.5 Thesis Outline

1. Chapter Two

   This chapter is mainly concerned with the literature review of this project. Briefly, it explains the USLE model and GIS application for this project.

2. Chapter Three

   This chapter presents the overall used methodology and solution to generate the soil erosion maps. It explains all the major steps involved with this project starting from data gathering to output of the analysis.

3. Chapter Four

   In this chapter, the results of this project are present. They show the effects of different cover factors and the recommended soil conservation practices to be practiced.

4. Chapter Five

   The conclusion of this project and proposal for the future works are given.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction to Soil Erosion

Soil, the most basic of all resources, is nonrenewable. Once lost, it is difficult to replace within the foreseeable future. New soil formation, development of biologically productive and economically fertile soil from parent rock, is a slow process measured only on a geological time scale. The soil formed over hundreds to thousands of year can be blown or washed away in a single climatic event.

Soil erosion is one of the most serious environmental problem where it remove soils rich in nutrients, increase natural level of sedimentation in the river and cause flash flood at the construction area. The rapid erosion of soil by wind and water has been a problem since man began cultivating the land. Recognising that an accurate figure is hard to establish, Oldeman et al. (1991) suggest that about one-sixth of the world's usable land has already been degraded by water or wind erosion. Soil erosion can also cause off-site environmental problems such as increased dust in the air, increased transport of sediments to rivers and lakes, and siltation of reservoirs. Until today, soil erosion remains a problem in most parts of the world.

The term 'erosion' often is used as an all-inclusive word to describe the wearing down of landscape. The word erosion is derived from the Latin word *erosio*, meaning 'to gnaw away'. Erosion can be defined as the detachment or entrainment of soil particles, thus distinguishing it from deposition or sedimentation and sediment transport. Soil loss and sediment yield is limited by the transport capacity of the runoff. As runoff flows through watershed, changes in topography, vegetation and soil characteristics often reduce this transport capacity.

Sediment is introduced into our water resources through the erosion process. It is the number one polluter, quantity-wise at least, of our water resources. Sediment itself is detrimental to fish propagation and recreational uses of lakes and streams. Sediment also transports chemicals, especially phosphorus, which cause rapid eutrophication (ageing) of those bodies of water.

In many tropical countries, heavy rainfall and effects of upstream changes in land use have always caused detrimental consequences on reservoirs. Sedimentation and siltation of particles within the reservoirs are the main problems that have been reported by many researchers (Nik et al. 1993). Deposition of this sediment could lessen the reservoir capacity and therefore affecting the economic life (Mustafa 1987). Sedimentation can also affect a reservoir's water quality and reduce its flood control, water supply, hydropower and recreation benefits.

For a dam, sedimentation deposition can reduce its stability and affect the operation of low-level outlet works, gates and valves. The abrasive action of sediment particles can roughen the surface of release facilities and cause cavitation and vibration. These effects can jeopardise a dam's integrity and safety.

Erosion (also sedimentation) is a non-uniform, unsteady process with both transportation and deposition occurring simultaneously. The forces causing water erosion can be categorised as:

1. Attacking Forces:

Those cause detachment and transport of soil particles. Rainfall and runoff produce these forces. For a unit mass of water, larger raindrops and faster flowing runoff have greater energies for causing erosion.

2. Resisting Forces:

Those which tend to either stabilise the soil (increased cohesion or weight) or reduce the magnitude of the attacking forces (increased infiltration, better canopy, or increased surface roughness). Vegetation is especially important in that it intercepts rainfall, restrains soil movement, improves infiltration, decreases runoff velocities, and improves soil aggregation.

The process of soil erosion by rainfall and runoff mainly consists of the detachment and transport by raindrops and runoff. Models available in the literature for soil eosion can be grouped into two categories: (i) physically-based models; and (ii) lumped models. In the physically-based models the ground surface is generally separated into inter-rill and rill erosion areas. Detachment over inter-rill areas is considered to be by the impact of raindrops because the flow depths are shallow, while runoff is considered to be the dominant factor in rill detachment and sediment transport over both rill and inter-rill areas.

The physically-based models include AGNPS (Young et al. 1987), ANSWERS (Beasley et al. 1980), WEPP (Nearing et al. 1989) and SHE (Wicks & Bathurst 1996). Physically-based model are expected to provide reliable estimates for the sediment yield. However, these models require the co-ordinated use of various sub-models related to meteorology, hydrology, hydraulics and soil. Therefore, the practical application of these models is still limited because of uncertainty in specifying model parameter values and also due to the difference between the scales of application i.e. a catchment vs a field (Wu et al. 1993).

Alternatively, lumped models such as the Universal Soil Loss Equation (USLE) (Wishmeier & Smith, 1978), Modified Universal Soil Loss Equation (MUSLE) (Williams 1978) or Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1991), combine the erosion of all processes over a catchment into one equation. Rainfall characteristics, soil properties and ground surface conditions are represented by empirical constants in these methods. The lumped methods of the sediment yield estimation are in frequent use in many parts of the world (Kothyari et al 1996).

There is ample evidence that the USLE yields a good estimate of the amount of detached soil (surface erosion) at the plot scale (Wishmeier & Smith 1978). However, in the case of a catchment, part of the eroded soil is deposited within the catchment before its outlet. Nevertheless, the catchment can be sub-divided into sub-areas for representing spatial heterogeneity. Surface erosion as computed using the USLE in the sub-areas can be routed to the catchment outlet using any appropriate procedure.

| Scale of Analysis | | | Evidence |
|---|---|---|---|
| Macro | Meso | Micro | |
| Climate | Lithology Relief | | Sediment Yield of Rivers |
| Climate | Lithology Relief | Micro-climate Lithology (soil) | Drainage Density |
| Climate | Altitude Relief | | Studies of Erosion Rate |
| Climate | | | Studies of Soil Loss from Hillslopes |

*Table 2.0*

*Factors influencing soil loss at different scales*

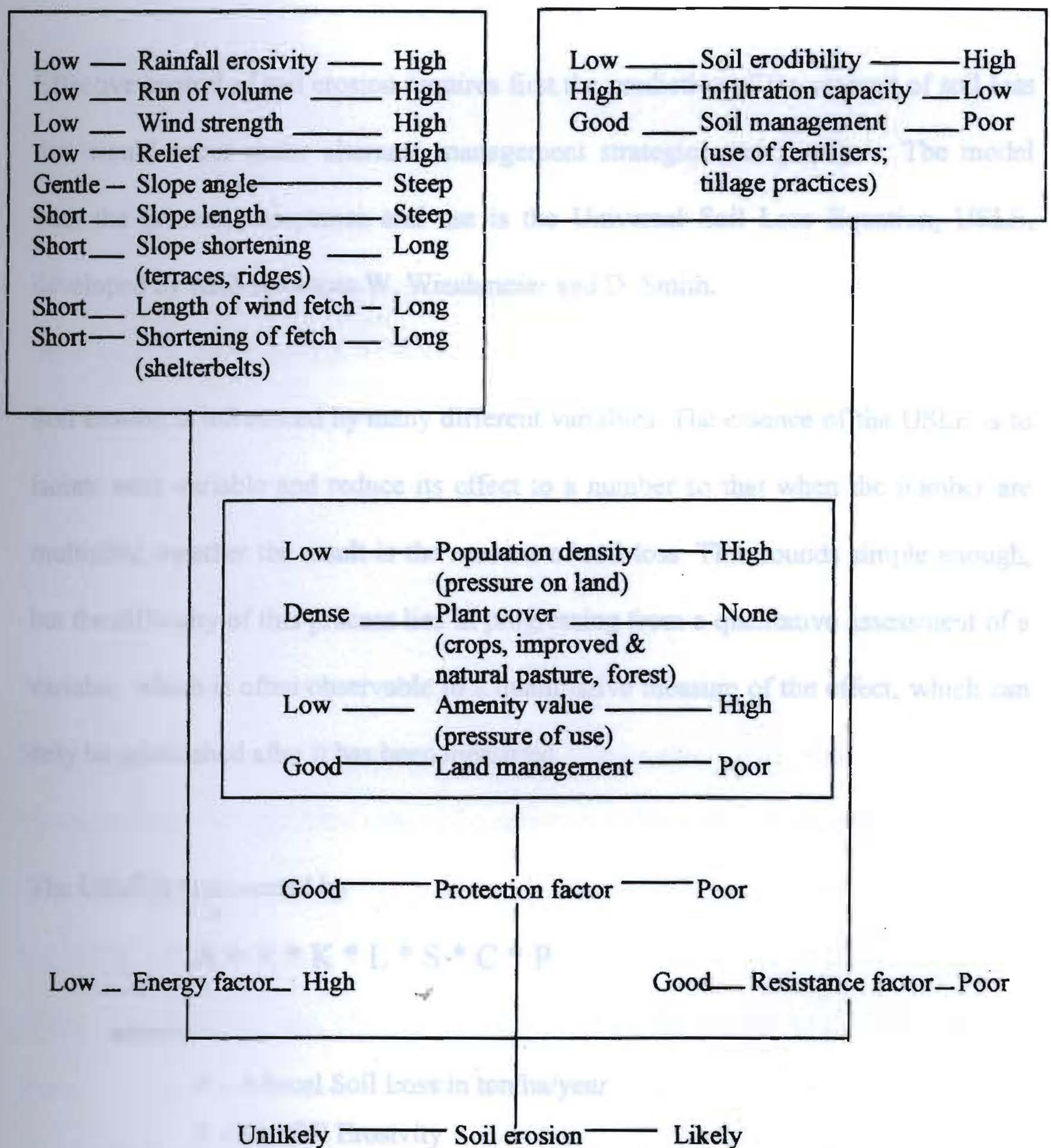



*Figure 2.0*

*Factors affecting soil erosion*